Tests of an Optical Transition Radiation Detector for High-Intensity Proton Beams at FNAL

V. E. Scarpine, A. H. Lumpkin[†], W. Schappert, G. R. Tassotto
Fermi National Accelerator Laboratory, Batavia, IL 60510
[†]Argonne National Laboratory, Argonne, IL USA 60439

Abstract

Initial test results are presented of a prototype Optical Transition Radiation (OTR) detector under development at Fermi National Accelerator Laboratory (FNAL). The purpose of this prototype detector is to evaluate the feasibility of using OTR imaging of proton (or antiproton) beams in transport lines for beam position and shape measurements. A secondary purpose is to develop experience in designing, constructing and operating a camera and optics system in high radiation environments. Measurements are made of 120 GeV proton beams with up to $5x10^{12}$ particle intensities. Data is presented of OTR with titanium and aluminum foils. OTR images are analyzed for beam position and shape.

Introduction

FNAL is currently pursuing a number of projects where either beam luminosity for the Tevatron collider (Run II) or proton intensity for neutrino experiments requires careful tracking of beam properties throughout the facility. Particle-beam diagnostic techniques based on optical transition radiation (OTR) have been demonstrated at a number of facilities over a wide range of beam energy (or Lorentz factor, gamma). The feasibility of using OTR imaging for the intense proton beams is based on comparison to electron-beam results at the Advanced Photon Source (APS) linac [1] and proton-beam results at CERN [2]. The scaling on gamma and the charge intensity indicate significant levels of OTR will be generated by the generally lower gamma but higher intensity (5×10^{12} p) proton beams.

Optical Transition Radiation

Optical transition radiation is generated when a charged particle transits the interface of two media with different dielectric constants (e.g., vacuum to dielectric or vice versa) [2, 3]. The effect is a surface phenomenon that can be understood as the collapsing of the electric dipole formed by the approaching beam charge and its image charge in the metal at the surface. As the fields readjust, pulse radiation is emitted. We then can use imaging techniques to determine beam size and position.

Prototype FNAL OTR Detector

We have recently directed our attention towards a measurement of the 120-GeV proton beams in the AP1 transport line upstream of the antiproton production target. At this location there is an air gap in the transport line as part of a vacuum isolation of the downstream Be vacuum window and the rest of the beamline. At the air-gap location the beam is not tightly focused, and the two Ti foil vacuum windows on either end of the gap establish the survivability of foils at this location.

The detector uses a 12μ Ti or 20μ Al foil in the air gap at 45° to the beam that serves as the OTR generator screen. The foil mount has the ability to tilt in order to optimize OTR to the camera. A lens system collects the OTR to the in-tunnel CID camera. The CID camera is a standard RS-170 format and operates at 30 image frames per second. The camera/optics combination produces a pixel size of ~100x100μ at the foil. The prototype OTR detector is in final stages of assembly and will be placed in the air-gap by early June.

Images of OTR are processed to produce values of beam position and size. Image processing techniques are used to remove hot pixels generated by background radiation. The system Point Spread Function is measured and used to improve the resolution of OTR images.

The multiple Ti foils at this location produce a high radiation environment with ~6K Rads/week being delivered to the camera and optics. Because of this radiation, both quartz and standard optical glass lenses are tested for image quality and radiation effects. The CID camera has been shown to operate to a total dose over 1 MRads.

The beam properties for 120 GeV protons have been compared to the known electron beam case at APS. Comparing gamma between the beams, a proton intensity of 5×10^{12} particles indicates about 10^3 times more light than the electron cases. However, the reflectivity of Ti is less than the Al mirror used in the electron beam case, and the proposed CID camera is less sensitive to light than CCD technology. These factors reduce the system sensitivity by 50-100, but there still remains a strong optical signal.

Future Systems

Following a successful demonstration of this prototype system, a three-screen emittance measurement and Beta-function matching configuration will be installed between the main injector and the Tevatron to measure proton and antiproton bunches. This would be used to evaluate and optimize beam conditions in support of the FNAL collider run. Other possible OTR applications involve the proton transport lines that support the neutrino experiments such as NuMI.

References

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